ERCOT AGS ESR Requirements

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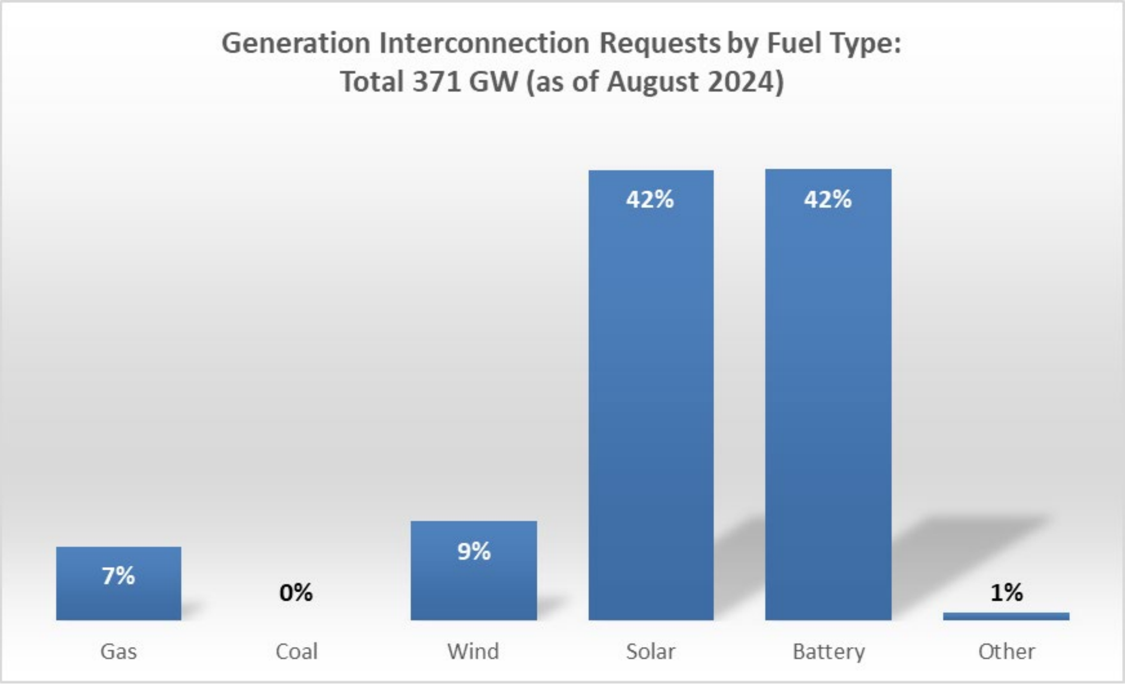
Introduction

- As IBRs become increasingly prevalent in ERCOT grid, the absence of online conventional synchronous generation resource support underscores the necessity for efforts to ensure stable grid operation
- Efforts to maintain grid reliability under increasing IBR penetration include:
  - Synchronous condensers project endorsed in Dec 2023
  - PGRR109 model review process effective in May 2024
  - NOGRR245 enhancing operating requirements approved in Oct 2024
- Effort to adopt Advanced Grid Support Inverter-Based Energy Storage Resources (AGS-ESR)
  - ERCOT contracted Electranix in late 2023 to help develop the functional specification and test framework for AGS-ESR
  - Electranix presented preliminary AGS-ESR functional specification and test framework at the July IBRWG. ERCOT also presented the next steps for adoption proposal.
  - ERCOT presented a draft proposal for AGS-ESR at the Sep IBRWG and posted the ERCOT AGS-ESR Test Requirement report in the IBRWG website

Generation Interconnection Requests

- As of August 2024, approximately 93% of new interconnection requests are Inverter-Based Resources (IBRs)
- Almost 42% of the interconnection requests are Energy Storage Resource (i.e., Battery)



Source: ERCOT GIS Report

- With minimum impact to the hardware, AGS-ESR can enhance grid stability, reduce generation curtailment due to stability constraints, reduce the severity of grid disturbance

Next Steps and Tentative Timeline

- ❑ Today, ERCOT will present details on the functional specification and test requirements and will invite feedback and comments from stakeholders

  - Comments to shun-hsien.huang@ercot.com , sunwook.kang@ercot.com , and Yunzhi.Cheng@ercot.com

- ❑ ERCOT plans to submit the PGRR and NOGRR for the stakeholder review by 2024. Consequently, the existing DWG Procedure Manual will need to be updated to incorporate the AGS-ESR model quality test requirements.

Test Requirements of AGS-ESR

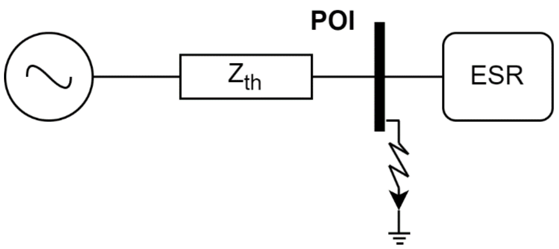
- ERCOT recommended two types of model tests for assessing AGS-ESR performance
  - Site-specific model quality tests (MQT)

Test #	Test Name	Testbench System	Applicable Software Platform
1	Flat start	TB1	PSCAD, PSS/E, TSAT
2	Phase angle jump	TB1	PSCAD
3	Small voltage disturbance	TB1	PSCAD, PSS/E, TSAT
4	Frequency change and inertia response	TB1	PSCAD, PSS/E, TSAT
5	System strength	TB1	PSCAD, PSS/E, TSAT
6	Large voltage disturbance	TB1	PSCAD, PSS/E, TSAT
7	Loss of synchronous machine	TB2	PSCAD, PSS/E, TSAT

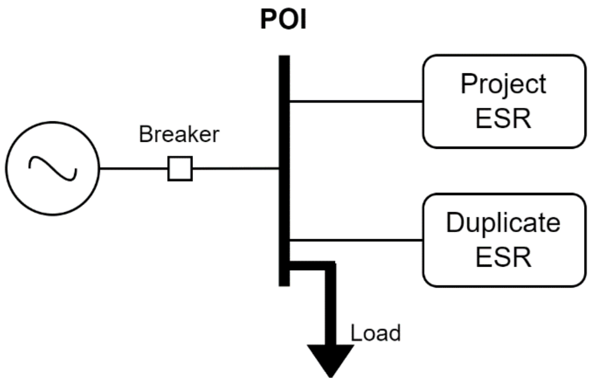
  - Unit model validation test (i.e., technology specific model test)
    1) Voltage Angle Step Test
    2) Step Change in Voltage
    3) System Strength Test
    4) Voltage Ride Through
    5) SubSynchronous Test

Testbenches for AGS-ESR

- Testbench 1 (TB1):
  - Ideal voltage source with controllable voltage (including magnitude, phase, and frequency),
  - Variable series impedance (Z_{th}) to adjust the short circuit ratio (SCR) of the connection point.



- Testbench 2 (TB2):
  - A voltage source with a circuit breaker to be able to disconnect the source from the system.
  - A constant impedance load with power factor of 0.95
  - The ESR model under test (project ESR)
  - A duplicate of the ESR model with the same size as the project ESR.



Test 1 - Flat Start Test

❑ Purpose of Test:

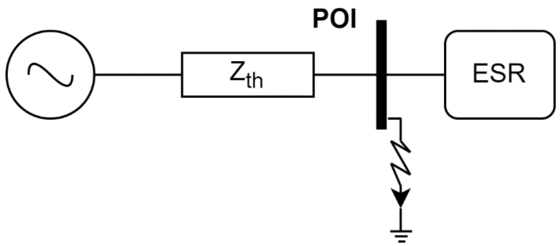
- Proper initialization of the model, verifying the steady state response, and ensuring the numerical stability of the simulation.

❑ Setup:

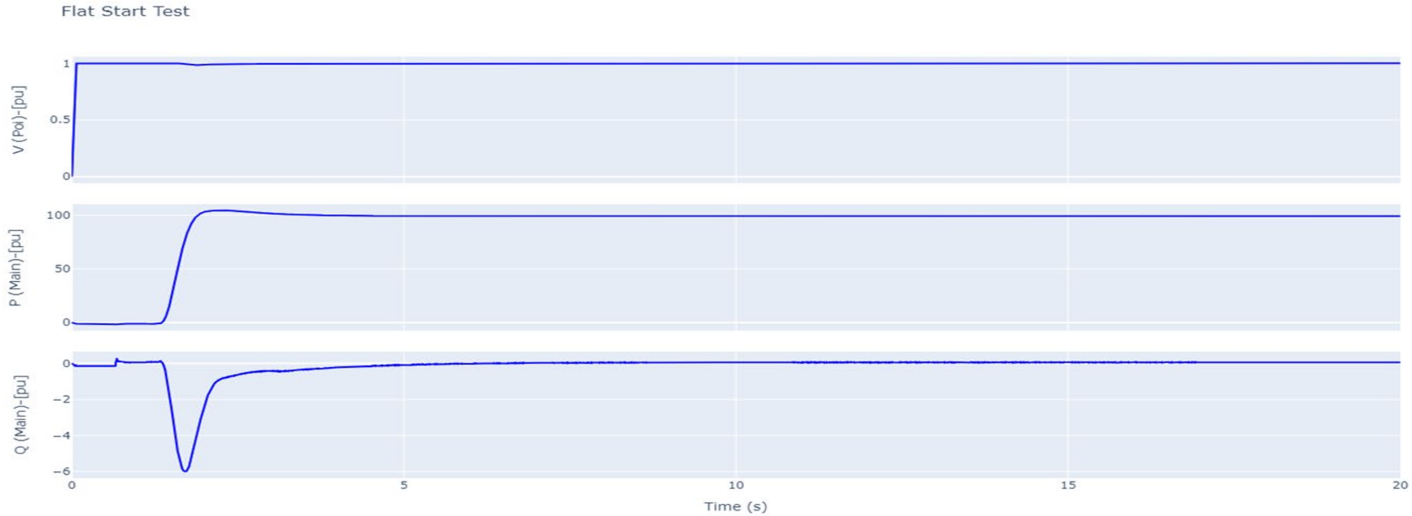
- Using Testbench 1, SCR at connection point is set to 3 with X/R of 6
- Initial dispatch of ESR is set to the max discharging for active power with approximately zero reactive power

❑ Test Sequence:

- No disturbance
- Simulate for a minimum of 20 seconds

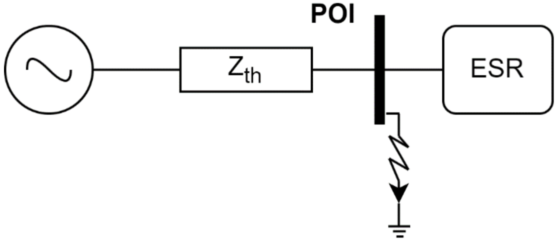


Acceptable Results

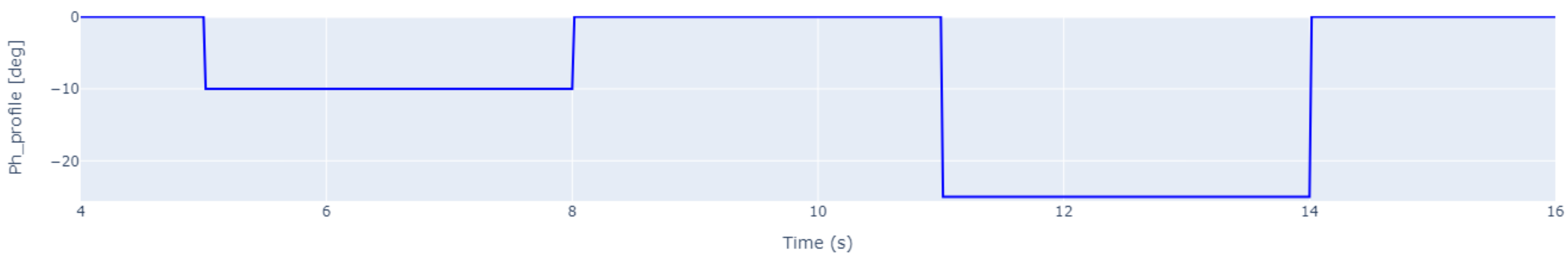


Test 2 - Phase Angle Jump Test

- Purpose of Test
  - Capability to maintain the voltage phasor and resist to angle change,
  - Stable behavior when it is working close to the maximum current limit
- Setup:
  - Using Testbench 1, SCR at connection point is set to 3 with X/R of 6
  - Initial dispatch of ESR is set to the max discharging for active power with approximately zero reactive power



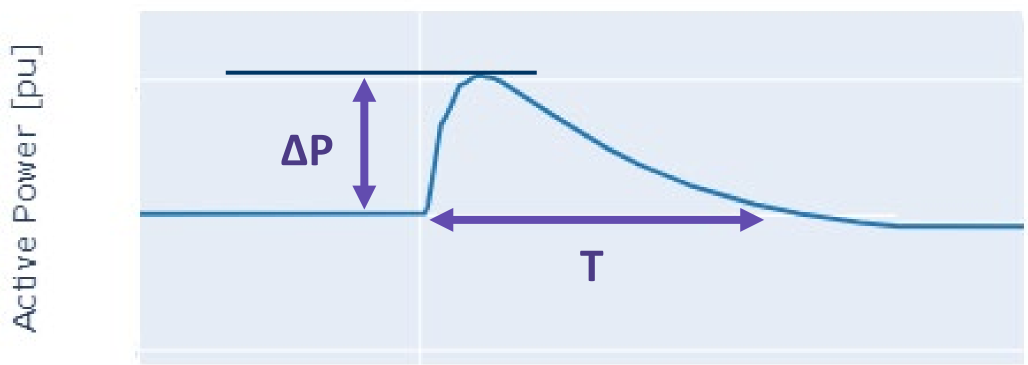
- Test Sequence:
  - Step changes to the phase angle of the 3-phase voltage source as follows:



Test 2 - Phase Angle Jump Test

- Success Criteria
  - Instantaneous active power output of the plant should quickly respond to oppose the angle change. The peak active power change should be at least 0.2 pu (based on rated active power) for each 10-degree voltage phase angle change, in opposing direction.

  Note: If the pre-event dispatch causes the plant to reach the current limit in the inverter when the angle jump is applied, the performance criteria described above may not apply. However, the active power must return to the pre-disturbance level in a stable manner without causing undue degradation of system performance. The active power must be more than or equal to pre disturbance level for at least 3 cycles.



Summary:

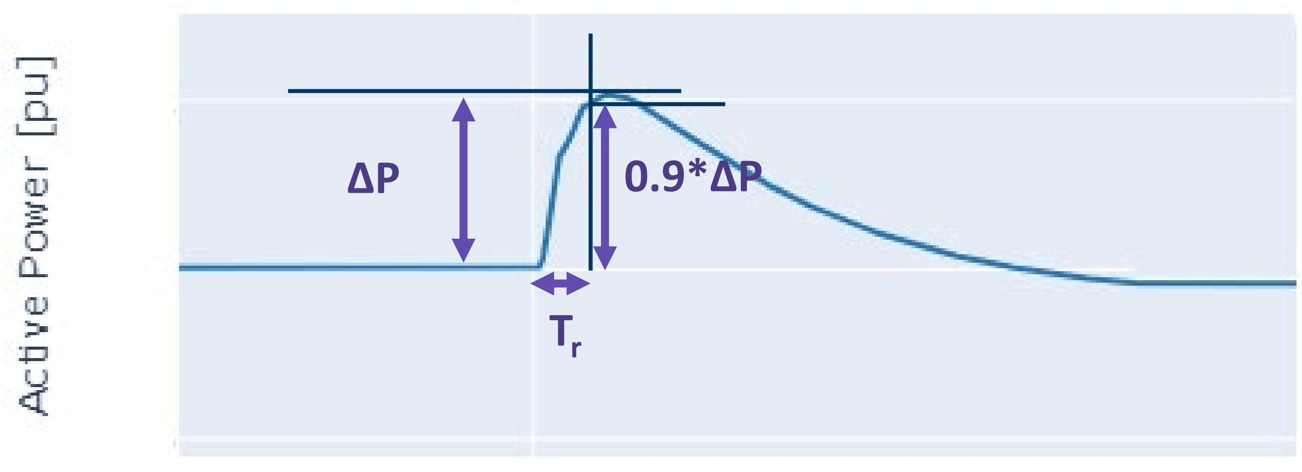
For 10-degree angle jump → $\Delta P \geq 0.2$ pu

For 25-degree angle jump → $\Delta P \geq 0.5$ pu

$T \geq 3$ Cycles

Test 2 - Phase Angle Jump Test

- For the 10-degree voltage phase angle jumps, response time to 90% of initial change in instantaneous active power should occur within one cycle



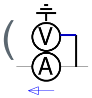
Summary:

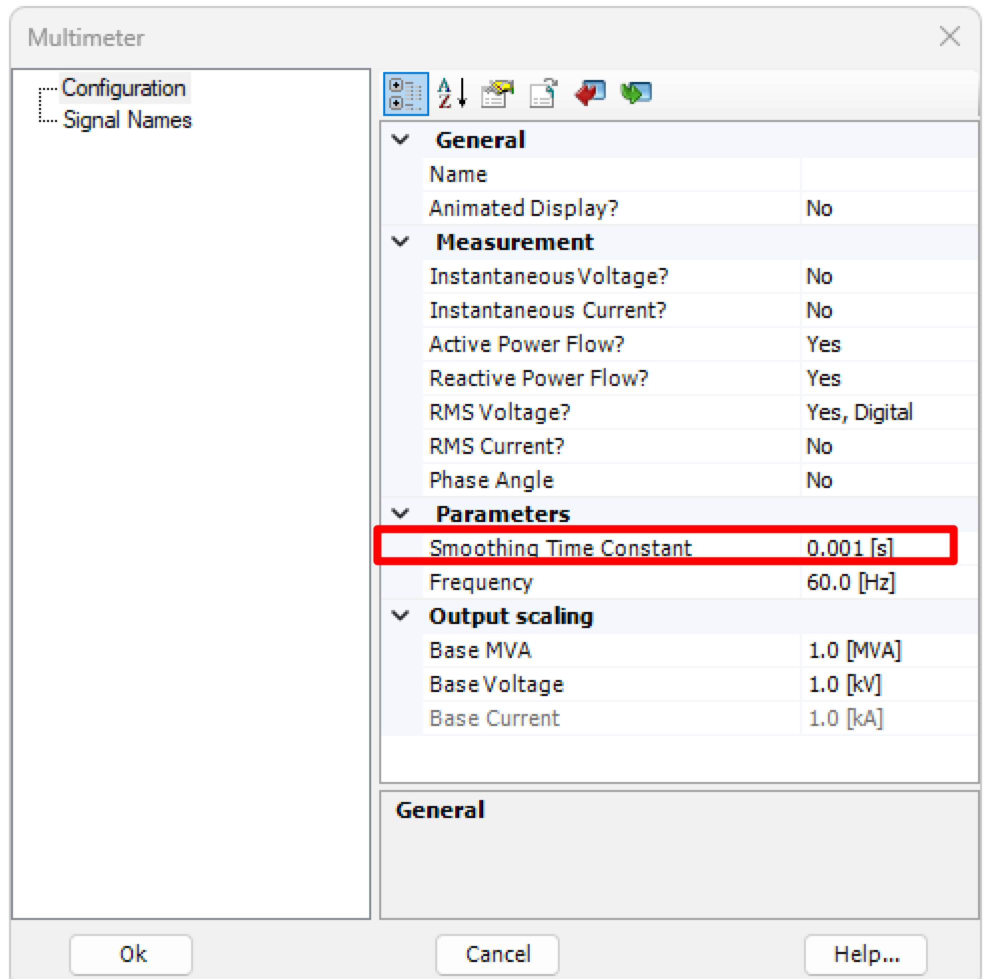
For10-degree angle jump
→ Tr ≤ 1 Cycle

ΔP: Initial change

- Any oscillation shall be damped

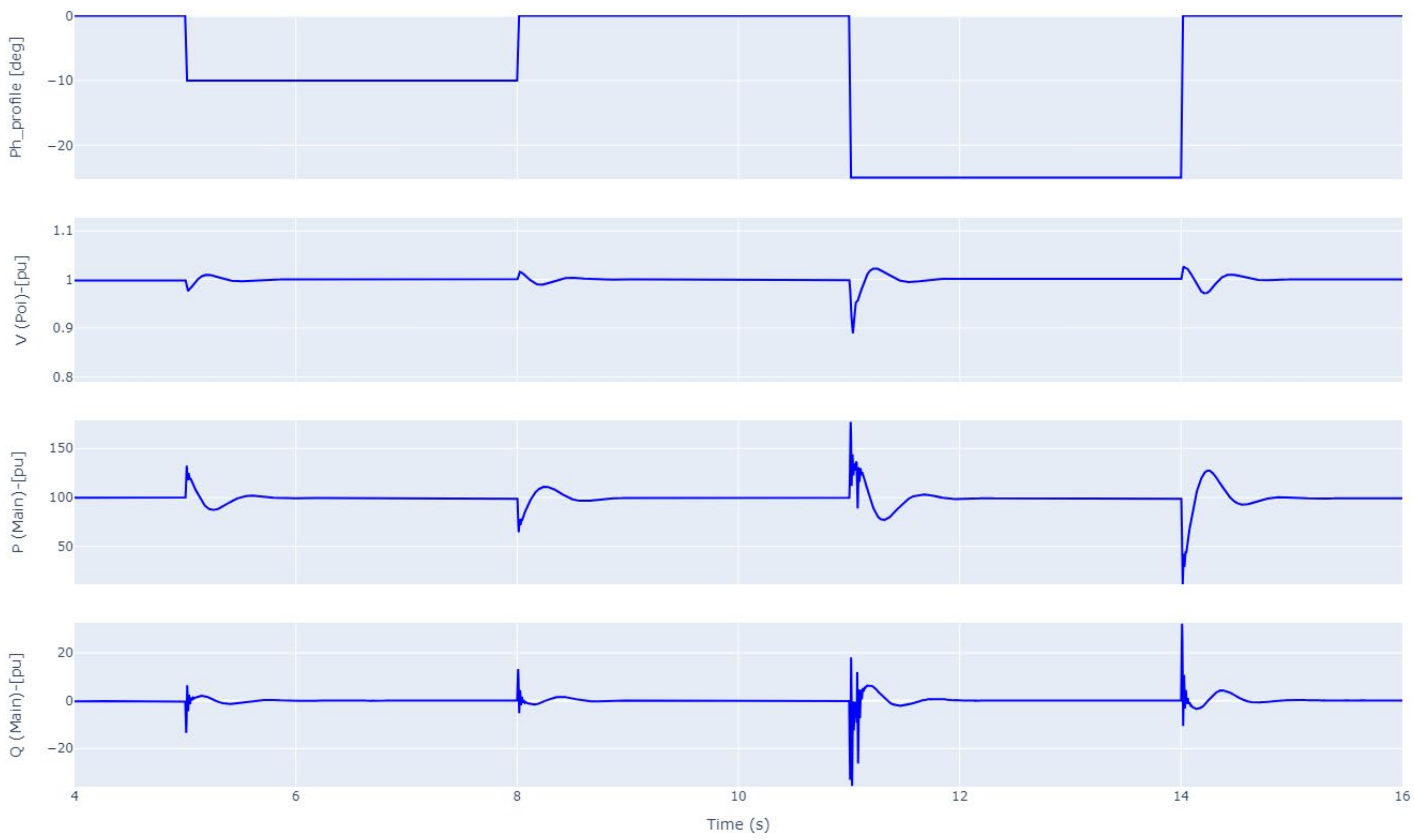
Test 2 - Phase Angle Jump Test

- For measuring electrical variables, e.g. V, I, P, & Q, in PSCAD a multimeter () is used
- It has a parameter called “Smoothing time constant”, with a default value of 0.02 s.
- It is recommended to have a smaller value, close to zero, to monitor the sub cycle phenomena.



Test 2 - Phase Angle Jump Test

- Example of Acceptable Results



Test 2 - Phase Angle Jump Test

- Example of Unacceptable Results

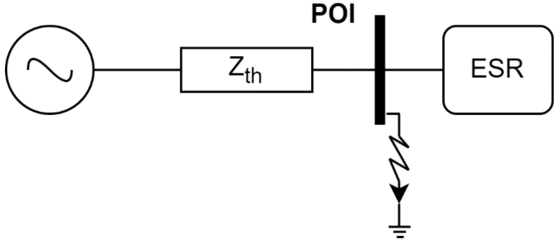
Test 3 - Small Voltage Disturbance Test

Purpose of Test

- Capability to resist change in voltage magnitude
- Reactive power response under small voltage step change

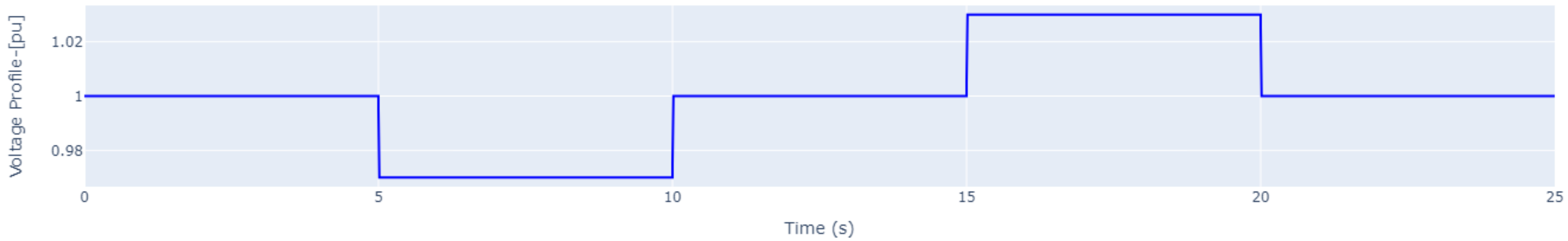
Setup

- Using Testbench 1, SCR at connection point is set to inf (Z_{th} =0)
- Initial dispatch of ESR is set to the max discharging for active power with approximately zero reactive power



Test Sequence

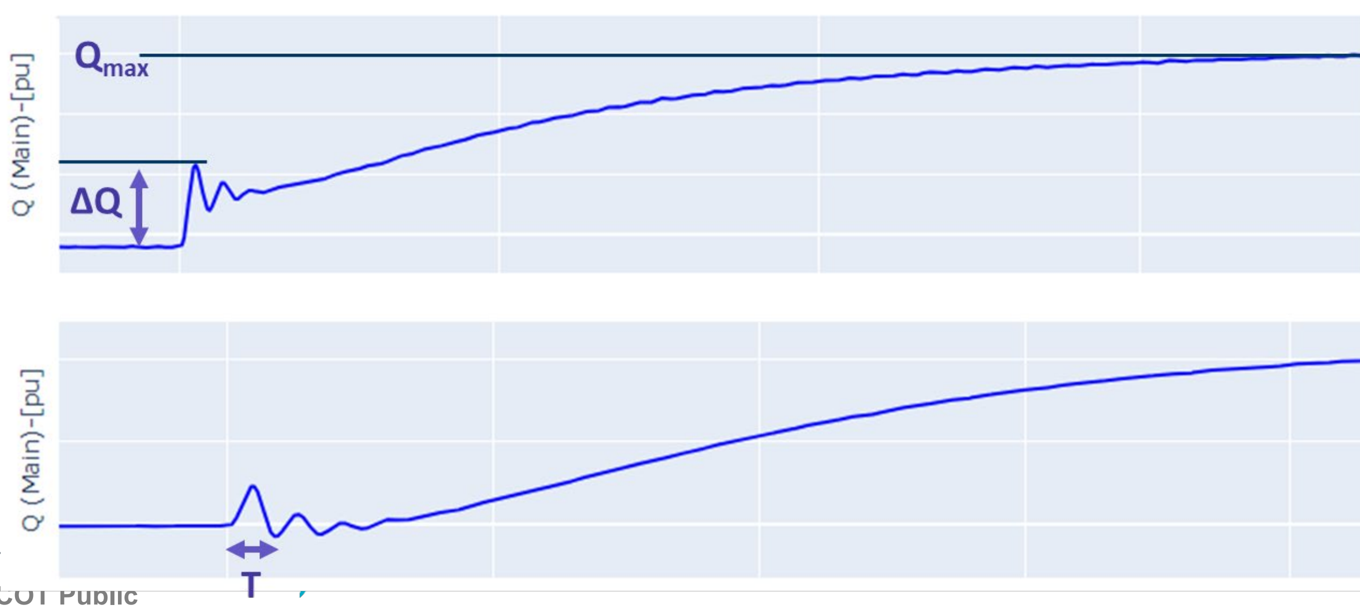
- +/- 3% instantaneous change of voltage magnitude of the source



Test 3 - Small Voltage Disturbance Test

- Success Criteria
  - Instantaneous reactive power output of the plant should quickly respond to oppose the voltage step change for each of the 3% voltage step changes, with an initial peak reactive power change of at least 0.03 pu on the rated power.

    Note: Reactive power does not return to the pre disturbance level within 6 cycles.
  - Response time to 90% of initial change (T_r) in instantaneous reactive power should occur within 1 cycle
  - Any oscillation shall be damped.
  - The final reactive power after each 3% step change is expected to reach to the maximum reactive capability of the plant in an attempt to regulate the original voltage set point at 1.0 pu.



Summary:

ΔQ ≥ 0.03 pu

T ≥ 6 Cycles

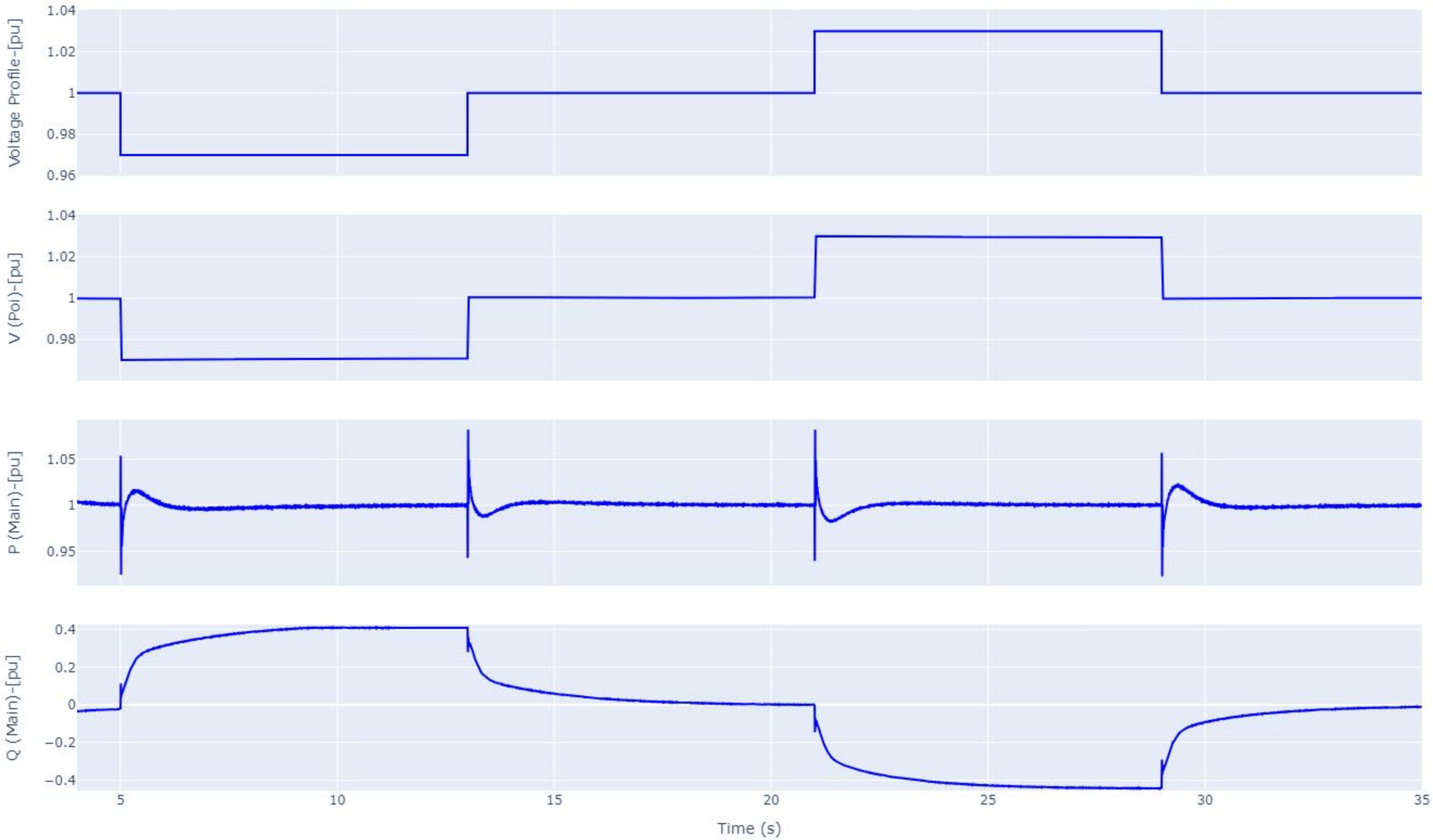
Tr ≤ 1 Cycle

Tr : the time Q reaches to 0.9* ΔQ

Reactive power reaches to Qmax

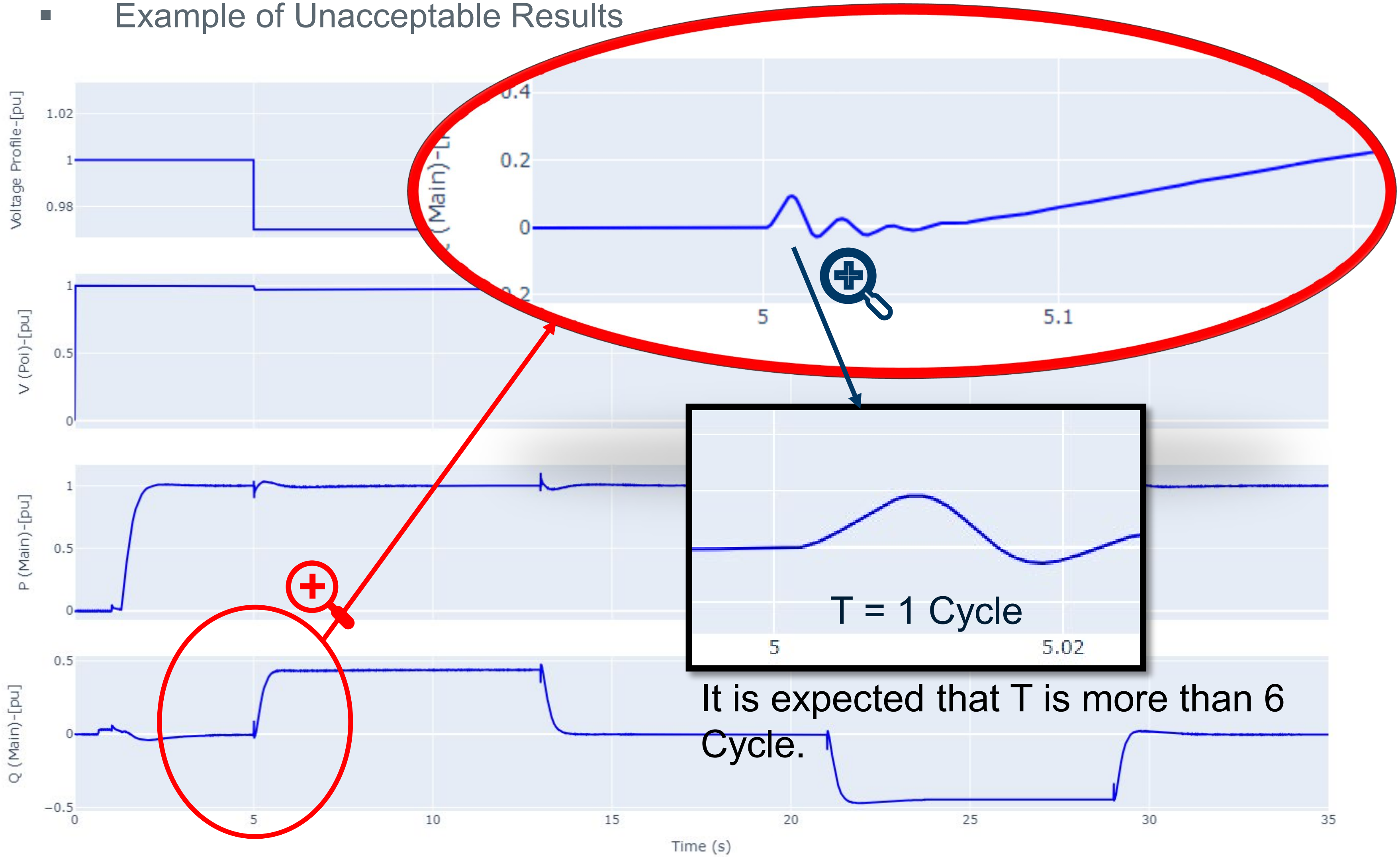
Test 3 - Small Voltage Disturbance Test

- Example of Acceptable Results



Test 3 - Small Voltage Disturbance Test

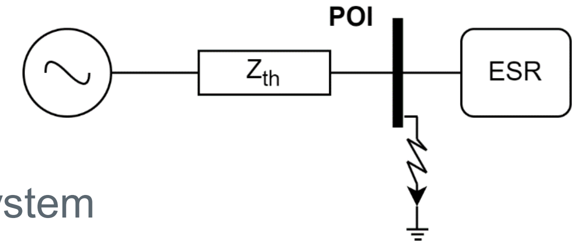
- Example of Unacceptable Results



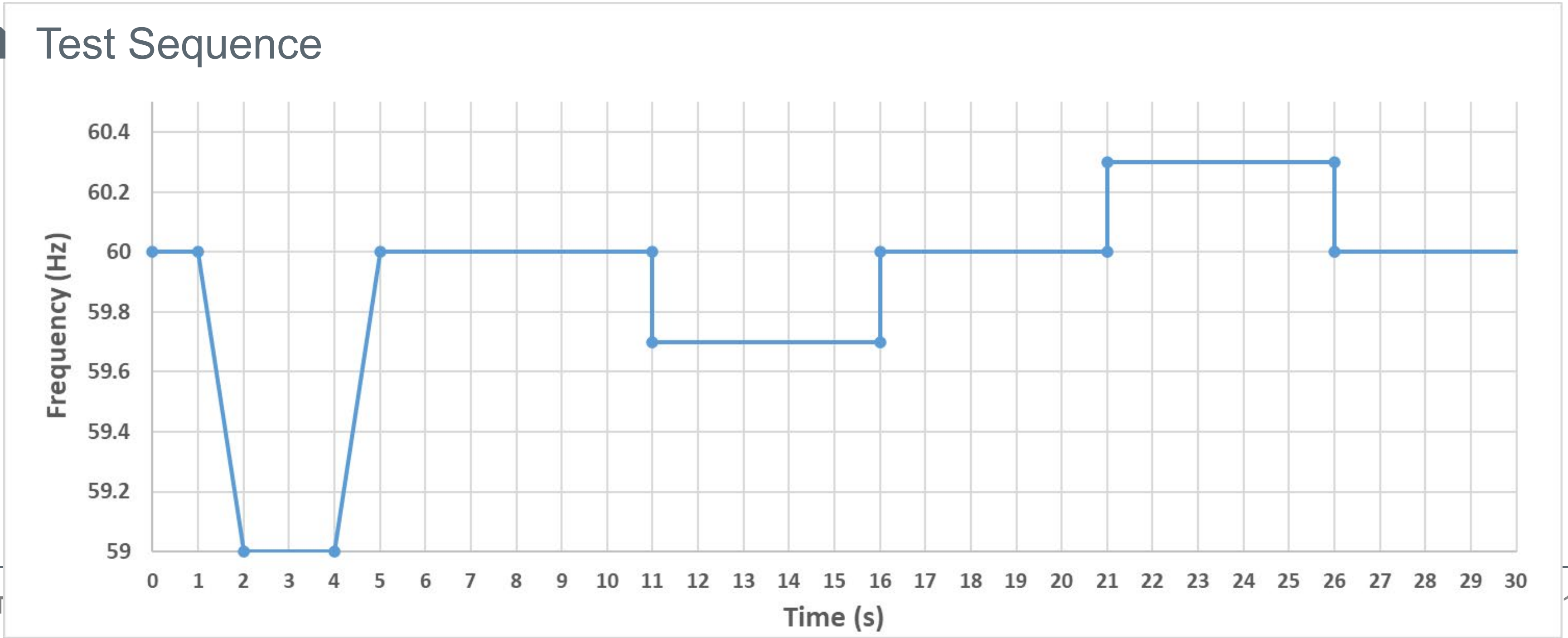
It is expected that T is more than 6 Cycle.

Test 4 - Frequency Change and Inertia Response Test

- Purpose of Test
  - Active-power frequency response capability of the ESR
  - Estimate inertia response



- Setup
  - Using Testbench 1, SCR at connection point is set to 3. System Equivalent X/R is set to 6.
  - Initial dispatch of ESR is set to zero for active power with approximately zero reactive power
- Test Sequence



Test 4 - Frequency Change and Inertia Response Test

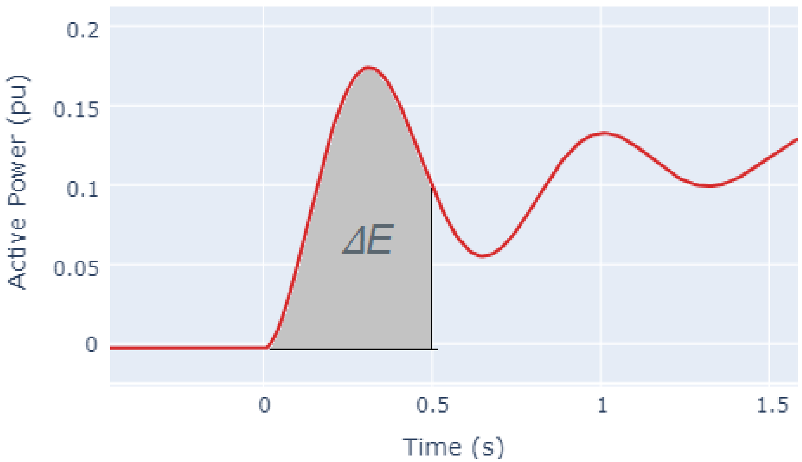
- Success Criteria
  - Plant real and reactive power output should be well controlled. System frequency and voltage should not oscillate excessively or deviate from steady state levels for any significant amount of time.
  - Voltage settles to a stable operating point when frequency is not ramping.
  - The equivalent inertia constant, calculated as below, should be greater than 2.5 s.

    $H \approx 60 * \Delta E$ [s] , where: ΔE is the area under the per unit active power production of the ESR from 0 to 0.5s, when the RoCoF is 1 Hz/s.

  - Active power should settle according to its frequency droop and deadband settings when frequency is not ramping.

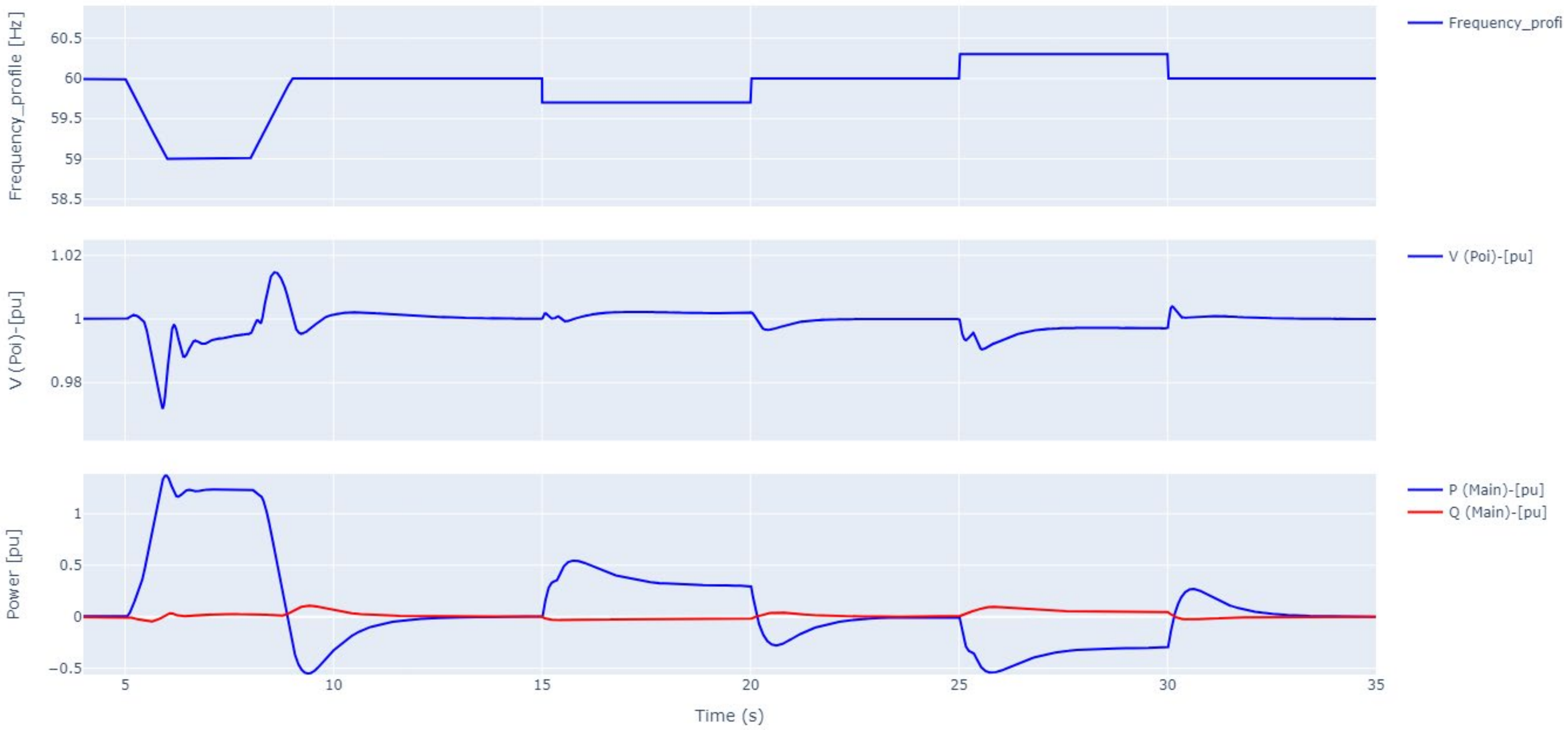
  Note: According to ERCOT Nodal Operating Guide Section 2.2.7 Turbine Speed Governors, the droop setting of ESR shall not exceed 5%.

  - Any oscillation shall be damped



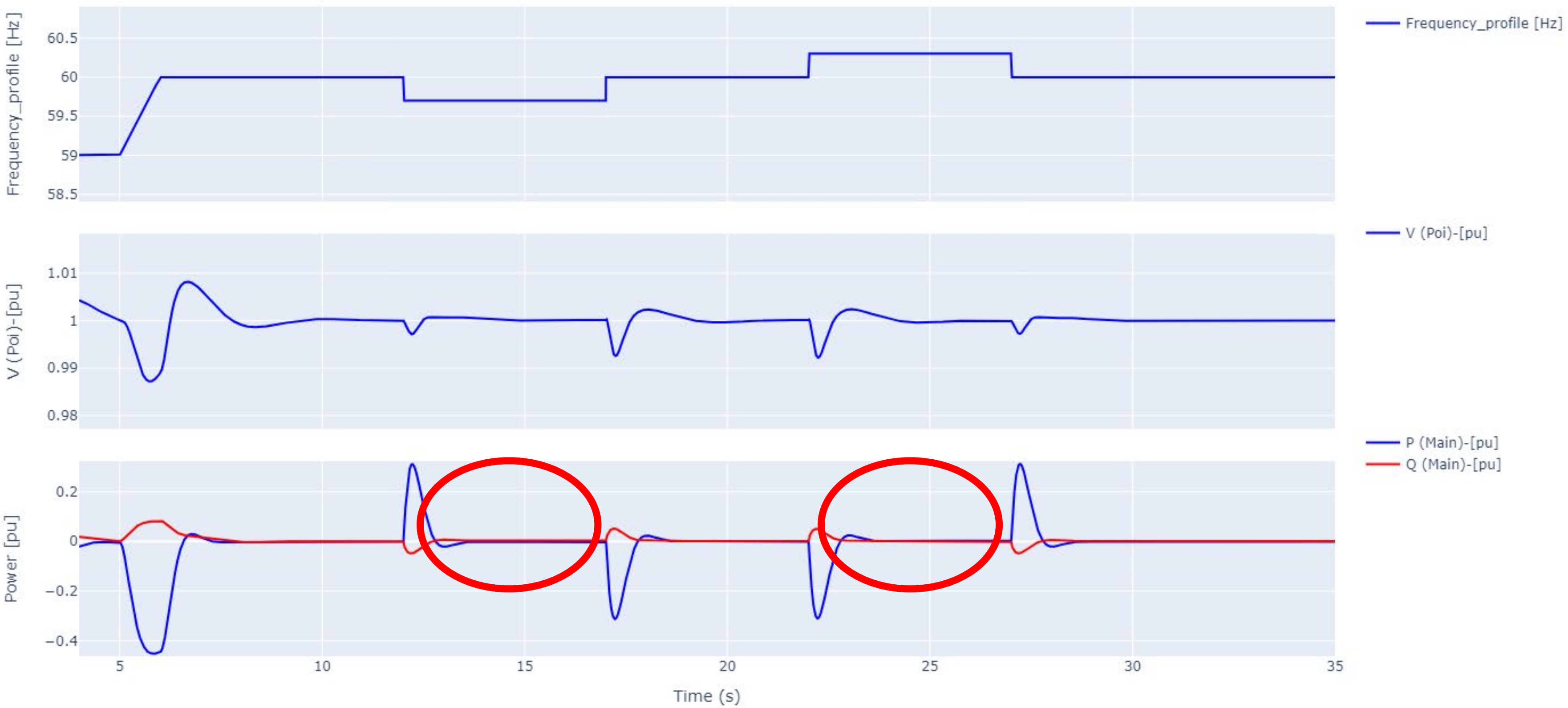
Test 4 - Frequency Change and Inertia Response Test

- Example of Acceptable Results



Test 4 - Frequency Change and Inertia Response Test

- Example of Unacceptable Results

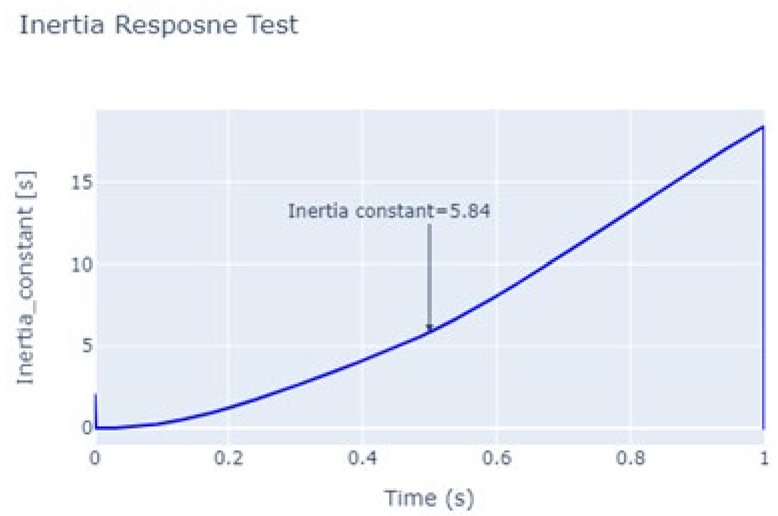


Active power should settle according to its frequency droop and deadband settings when frequency is not ramping.

Test 4 - Frequency Change and Inertia Response Test

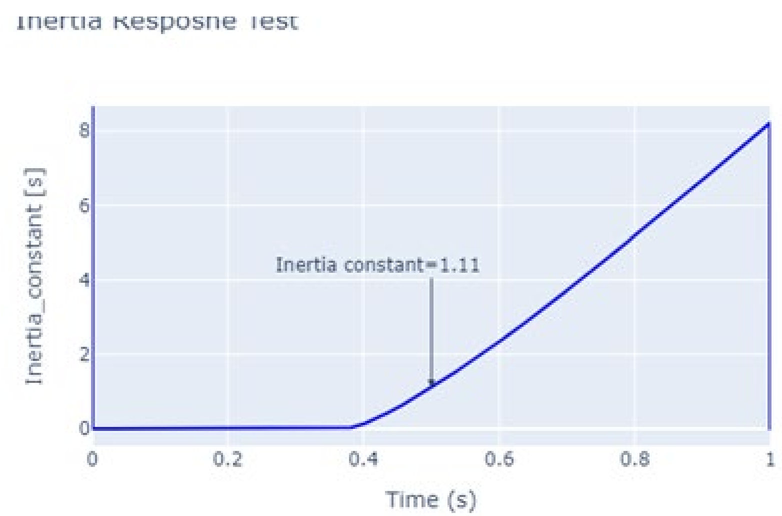
❑ **Acceptable Inertia Response**

Inertia constant @ 0.5 s is more than 2.5



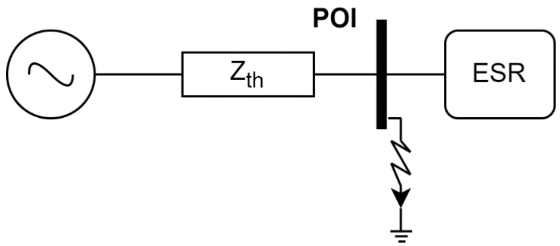
❑ **Unacceptable Inertia Response**

Inertia constant @ 0.5 s is less than 2.5



Test 5 - System Strength Test

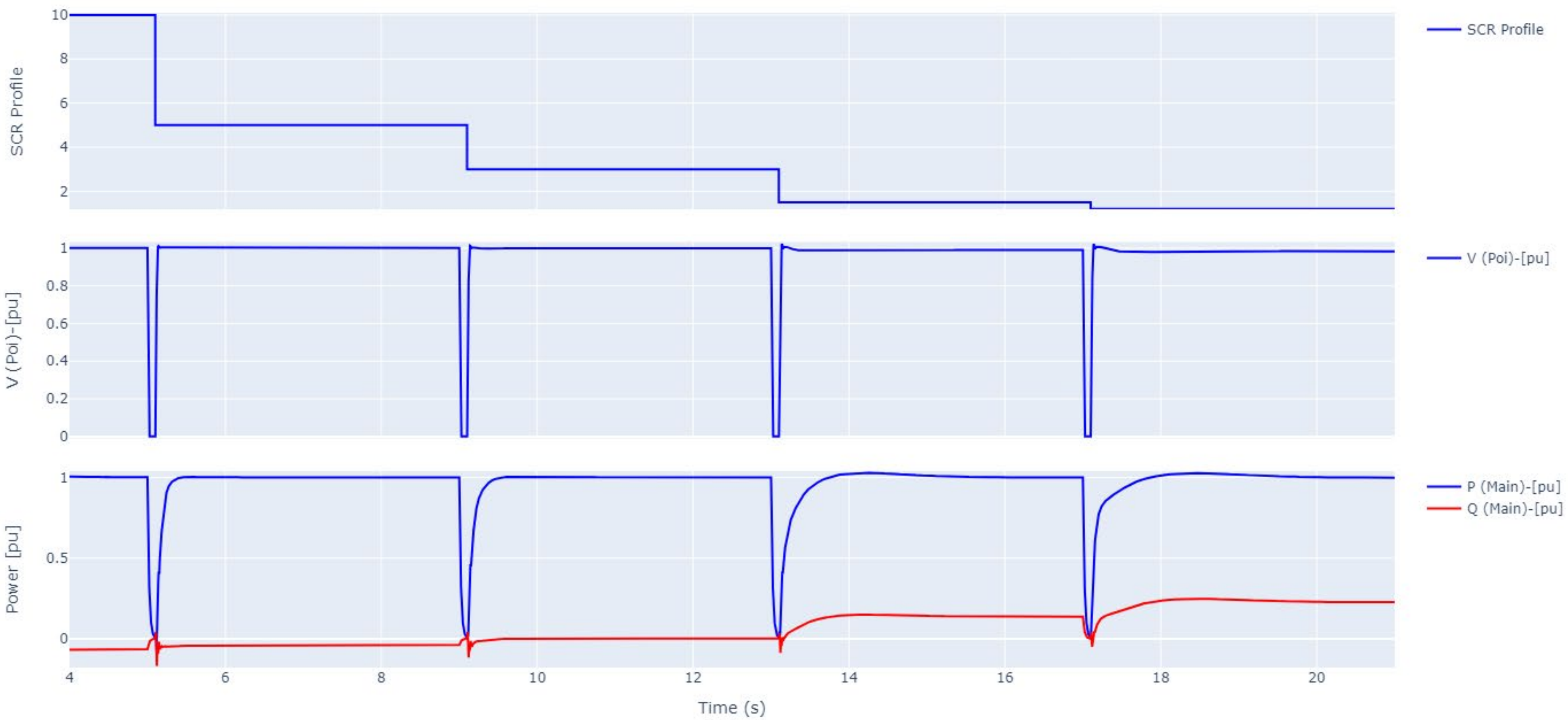
- Purpose of Test
  - AGS-ESRs shall demonstrate stable response for all tested SCR values from 10 to 1.2
- Setup
  - Using Testbench 1, initial SCR at connection point is set to 10. System Equivalent X/R is set to 6
  - Initial dispatch of ESR is set to the max discharging for active power with approximately zero reactive power



- Test Sequence
  - SCR at connection point stepped down repeatedly in this progression: 10, 5, 3, 1.5, 1.2
  - A 3-phase, bolted, 4-cycle fault is applied just before each SCR transition. The SCR transition occurs at fault clearing time

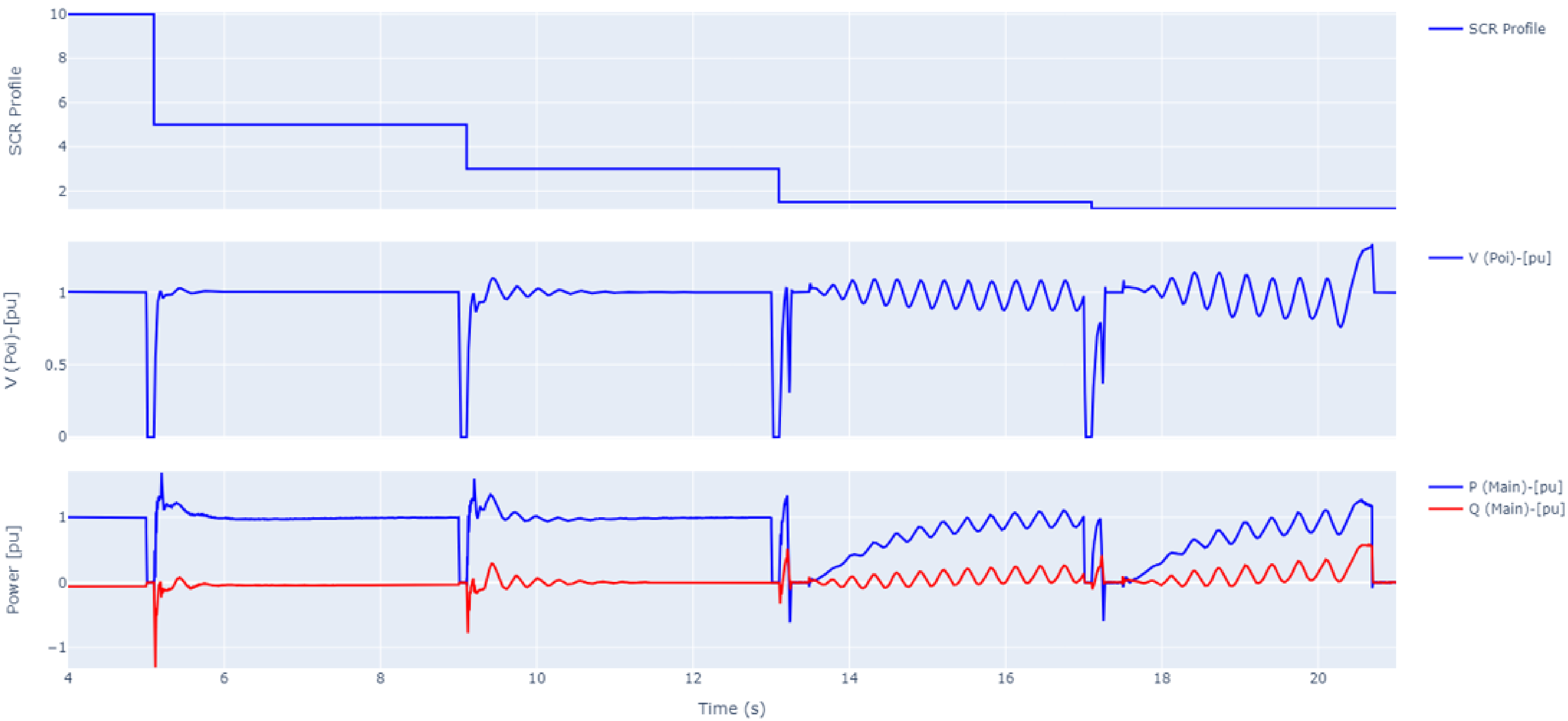
Test 5 - System Strength Test

- Success Criteria
  - Plant real and reactive power output and RMS voltage should be well controlled, and plant shall not trip nor reduce power or voltage for any extended period of time for all tested SCR range from 10 to 1.2, except during the fault
  - Example of Acceptable Results



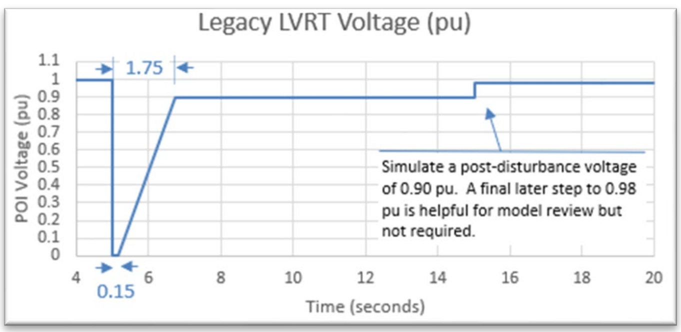
Test 5 - System Strength Test

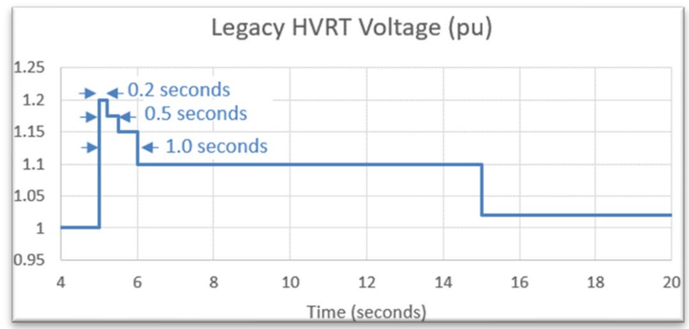
- Example of Unacceptable Results

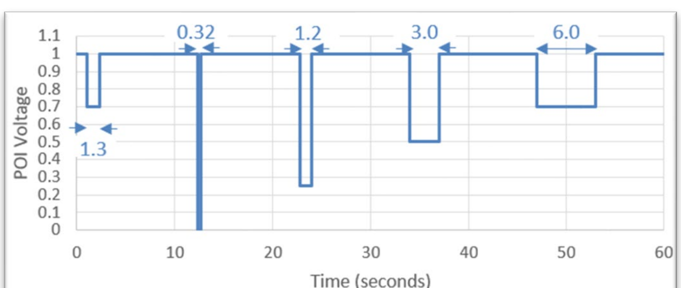


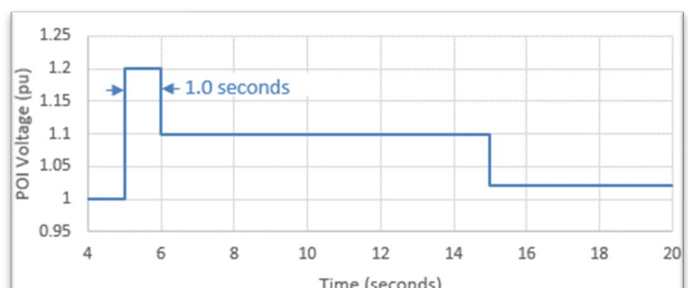
Test 6 - Large Voltage Disturbance Test

- ❑ Large voltage disturbance test for AGS_ESR are the same as existing IBRs.
  - ▪ Low voltage ride-through (LVRT)
  - ▪ High voltage ride-through (HVRT)
- ❑ Details are described in the DWG Procedure Manual



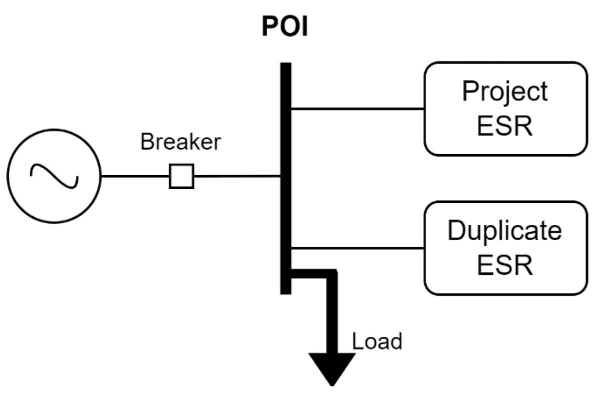






Test 7 - Loss of Synchronous Machine Test

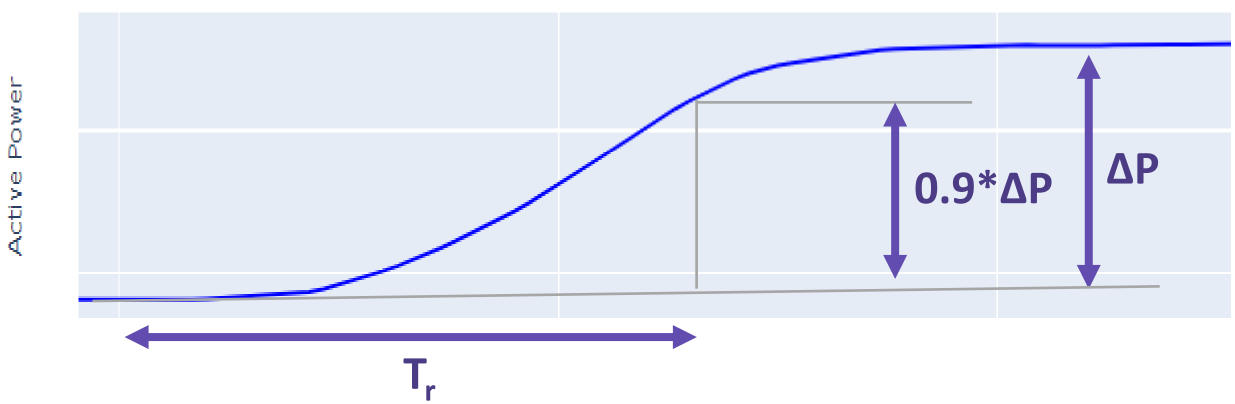
- Purpose of Test
  - Ability to form voltage and work in parallel with another AGS-ESR
  - It is not intended to examine the black start capability of AGS-ESR nor to require AGS-ESRs operate on a grid without synchronous resources
- Setup
  - Use Testbench 2. Dispatches (pu based on project plant rating) are as follows:
  - Scenario 1: P1 = 0.3 pu discharging, P2 = 0.1 pu discharging, and L = 1.3 pu
  - Scenario 2: P1 = 0.6 pu charging, P2 = 0.4 pu charging, and L = 0.7 pu
  - Scenario 3: P1 = 0, P2 = 1 pu discharging, and L = 1.65 pu
- Test Sequence
  - Simulate the system until a stable response is achieved for the given scenario, ensuring there are no oscillations.
  - Disconnect the voltage source (no fault) and continue simulation for at least 10 seconds.



Impedance load (L), with power factor of 0.95

Test 7 - Loss of Synchronous Machine Test

- Success Criteria
  - Immediately following the disconnection of voltage source, both plants' output should be well controlled. System frequency and voltage should settle to a stable operating point (within 5 seconds) and be damped within 10 seconds, without excessive oscillation or deviation from steady state levels
  - Active and reactive power from each plant should move immediately to meet the load requirement, while response time to 90% (Tr) of initial change should occur within one cycle
  - Active and reactive power from each plant should move immediately and settle according to its droop setting

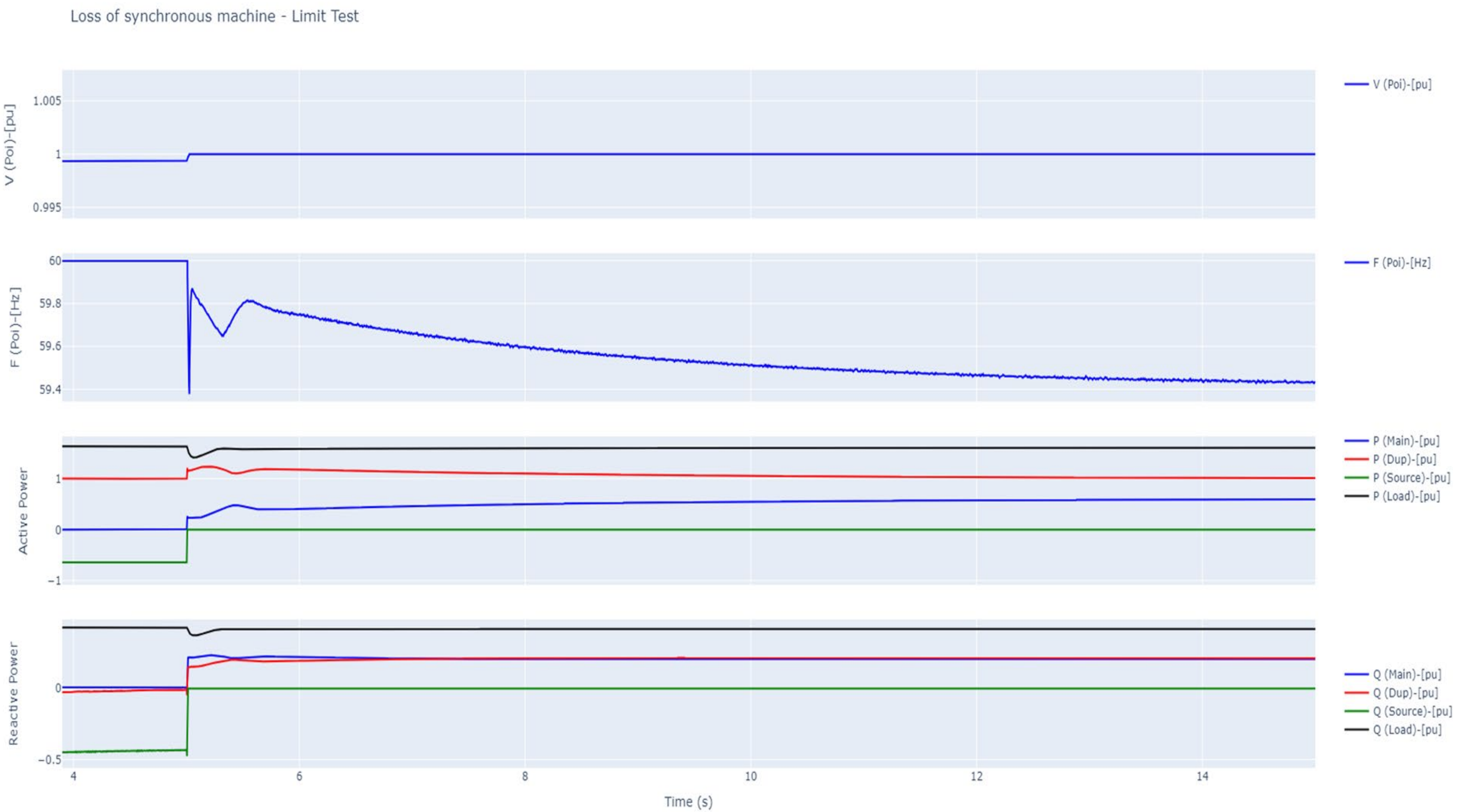


Summary:

- Settling time < 5s
- Oscillation damped less than 10 s
- Tr ≤ 1 Cycle

Test 7 - Loss of Synchronous Machine Test

- Example of Acceptable Results



Test 7 - Loss of Synchronous Machine Test

- Example of Unacceptable Results

Technology-Specific Unit Model Validation Tests

- Demonstrate the accuracy of the PSCAD models against actual inverter
- The testing is inverter- and control-strategy-specific but is not site-specific
  - Do not need to repeat for a new site, if the inverter model with the same control strategy has already had the approved test results
  - An inverter model that can work in either grid following or AGS mode needs to have the unit model validation test performed for the mode which is intended to be used for the ESR in the grid.
- Required tests
  - Voltage Angle Step Test
  - Step Change in Voltage
  - System Strength Test
  - Voltage Ride Through
  - SubSynchronous Test

Questions?

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Appendix: Quantifying Inertia Response of ESR

To estimate the inertia response of an ESR, the swing equation can be used.

$$\frac{2H}{\mathrm{f}_n} = \frac{\Delta P}{df/dt}$$

Where:

H is the equivalent inertia constat of the ESR in s,

f_n is the nominal frequency,

ΔP is the change of output power in pu based on the ESR MVA rating,

df/dt is the rate of change of frequency (RoCoF) in 1 Hz/s.

By changing the frequency of the controllable voltage source with a fixed rate, the output active power is changing as well. Therefore, the average ΔP (ΔPav) during the study time is used for quantifying the inertia constant:

$$H = 0.5\,\mathrm{f}_n \frac{\Delta P_{av}}{df/dt} = 0.5\,\mathrm{f}_n \frac{\frac{1}{T}\overbrace{\int_{t_0}^{t_0+T} \Delta P(t)\,dt}^{\Delta E}}{df/dt} = 0.5\,\mathrm{f}_n \frac{\Delta E/T}{df/dt}\ [s],$$

Considering, f_n =60 Hz, *df/dt* = 1 Hz/s, and *T*= 0.5 s, then:

$$H = 60 * \Delta E\ [s]$$